CHARACTERIZATION AND TREATMENT OF SNOWMELT RUNOFF FROM AN URBAN CATCHMENT

Research Publication No. 73

December 1978

Ministry of the Environment

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December, 1978

ABSTRACT

Snowmelt runoff from a 22.7 hectare urban catchment in East York, Metropolitan Toronto, Ontario, was studied during the winter of 1977/78. The study program comprised characterization of snowmelt and a preliminary evaluation of simple treatment methods in two mid-winter snowmelts (true snowmelts) and a period covering the final snowmelt of the season (true snowmelt and snowmelt/stormwater).

Storm sewer flow rates during true snowmelts were very low and at no time exceeded 8 L/s. Snowmelt/stormwater runoff rates were higher and varied according to prevailing precipitation, but did not exceed 80 L/s, which was far below the flow-rates experienced during rain-caused runoff.

Pollutant concentrations varied widely and for most pollutants were similar in range to those of rain-caused runoff. Because of road salting, chloride concentrations in the runoff were very high (up to 18,200 mg/L). As a result, even though the flow-rates in the storm sewer were low, the peak mass flow-rates of chloride were also high. The mass flow-rates of other parameters were all very low and could be considered almost insignificant compared to rain-caused runoff.

The storm sewer flows resulting from snowmelt did not contain significant quantities of settleable matter or larger-sized debris usually present in rain-caused runoff.

The applicability and effectiveness of natural and chemically assisted sedimentation for treatment of snowmelt were evaluated on-site at bench and pilot-scale. Due to the colloidal nature of most of the suspended matter, treatment by natural sedimentation achieved little pollutant removal. Chemically assisted settling using alum at dosages of 50 to 60 mg/L removed 84 to 98% SS, 80 to 97% VSS, 58 to 81% COD, 54 to 81% Total P, 80 to 86% Soluble P and 76 to 83% turbidity.

No change in bacterial levels occurred during natural settling. By contrast, alum flocculation and settling reduced fecal streptoccocci to very low levels while total and fecal coliforms were also reduced to some extent.

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1. CONCLUSIONS

1. Pollutant parameters tested for showed a wide range of concentration levels. The ranges of key pollutant concentrations in true snowmelt and snowmelt/stormwater were as follows:

	True Snowmelt	Snowmelt/Stormwater
Total Solids - mg/L	1110 - 31,740	228 - 746
SS - mg/L	130 - 840	65 - 261
DS - mg/L	980 - 30,900	155 - 600
BOD_5 - mg/L	18 - 46	9 - 26
BOD_{20} - mg/L	42 - 75	-
COD - mg/L	145 - 280	57 - 170
Total P - mg/L	0.3 - 0.9	0.4 - 0.75
Chloride - mg/L	510 - 18,200	45 - 276

2. Snowmelt and snowmelt/stormwater runoff contained little or no debris of the type usually found in rain-caused runoff, such as leaves, plastics, wood, metal cans and paper. The suspended matter present was non-settling and colloidal in nature.
3. Of eight trace metals analyzed for in the runoff, only lead showed elevated concentrations, and only in true snowmelt.
4. Indicator bacterial concentrations (total coliforms, fecal coliforms and fecal streptococci) were significantly lower in snowmelt than in rain-caused runoff from the same catchment.
5. Storm sewer flow rates during true snowmelt were very low - at the most reaching 8 L/s. Snowmelt/stormwater runoff rates were generally higher and more variable but did not exceed 80 L/s. These flow-rates were extremely low compared to those from even minor rain-caused storms.

6. During the final snowmelt, a large number of catchbasin covers were totally or partially covered by ice, making it difficult for free water to enter the storm sewer, thus attenuating the potential peak flow rates.
7. Even though flow rates in the storm sewer were low, the peak mass flow rates of chloride in snowmelt runoff were high because concentrations were very high. The mass flow rates of other parameters were all very low.
8. High initial levels of chloride at the start of individual snowmelts declined slowly with time toward levels typical of rain-caused runoff, as road salt was dissolved and transported to the storm sewer.
9. Because of the colloidal nature of most of the suspended matter, treatment of snowmelt by natural sedimentation achieved little pollutant removal.
10. Treatment of snowmelt by chemical flocculation and settling produced significant removal of pollutants. At alum dosages of 50-60 mg/L, the following percentage removals resulted:

	True Snowmelt	Snowmelt/Stormwater
SS	84	98
COD	58	81
Total P	54	81

11. Alum flocculation and settling reduced fecal streptococci to low levels (<10 counts/100 ml). Total coliform and fecal coliform concentrations were reduced only moderately, resulting in much higher final counts (3.0×10^2 and 1×10^2 counts/ml respectively).

2. INTRODUCTION

Awareness of stormwater-induced pollution has been slow in developing and only recently have programs been initiated to establish its relative magnitude and significance. Programs to date have been essentially geared towards study of runoff from rainfall.

Because there is a relative lack of data on urban snowmelt in the literature, the Wastewater Treatment Section decided to augment an ongoing program examining the treatment of rain-caused runoff from an urban catchment with separate sewers (1). This report presents the results of the supplementary program in which emphasis was placed on the characterization and simple physical-chemical treatment of runoff resulting from true snowmelt, and snowmelt induced by rainfall.

Based on visual inspection at the study site, observations and comments are also made on factors affecting the movement of runoff and pollutants overland, since prevailing surface conditions appeared to have significant and changing effect on the quantity and quality of snowmelt reaching the storm sewers.

3. OBJECTIVES AND SCOPE

The study was carried out over the 1977/78 winter season at the Barrington, East York urban catchment.

The major objective was to determine the pollutant reductions obtainable on snowmelt runoff by natural and chemically assisted settling at bench- and pilot-scale. A second objective was to characterize snowmelt runoff from the catchment.

Two types of snowmelts were encountered which have been defined as "true snowmelt" and "snowmelt/stormwater". "True snowmelts"

resulted from road salt application and/or above-freezing temperatures. Snowmelt/stormwater resulted when light rainfall supplemented or initiated the melting process.

4. LITERATURE REVIEW

While published data relating to snowmelt quality are scarce, no data on treatment could be found. With few exceptions, the various studies of snowmelt quality have addressed only those pollution problems associated with the use of deicing agents and with lead. In the United States, a study in Chicago indicated that during snowfalls, and with road salting, chloride levels in the runoff ranged from 11,000 to 25,000 mg/L (2). This study also showed that practically all the applied road salt eventually ran off. A Wisconsin study found that runoff had chloride levels in the range of 0 to 16 mg/L during summer months while winter runoff contained up to 10,000 mg/L (3). Other studies have shown that a variety of additives may be included in the road salt, including potential carcinogens - the additives may present worse pollution problems than the salt itself (4,5,6). The effects of the salt have included widespread damage to roadside soils, vegetation and trees, surface stream and lake contamination (7). Lead from automobile emissions tends to be deposited in the area of the road bed, and subsequently to be transported to the storm sewer and receiving waters during runoff periods. The presence of lead may induce toxicity in the runoff and thereby produce erratic BOD_5 results (8).

The Canadian literature on snowmelt characteristics from separate-sewered catchments includes reports from a previous study at the Barrington Avenue site (9) and from the Brucewood, North York (10) catchment. Selected quality data from these studies is presented in Table 1.

The data in Table 1 also include some results from a snowmelt characterization study at a 74-hectare (183-acre) catchment in Boulder, Colorado (11) - the only detailed study located in the United States literature. At Boulder, pollutant concentrations varied widely and storm sewer flow-rates depended on the prevailing daytime temperatures and hours of sunshine. Peak flow-rates of about 70 L/s usually occurred around noon, declining to a base flow of 4 L/s by late afternoon. In contrast to rain-caused runoffs, no first flush effects occurred during snowmelts.

Results from Boulder can be expected to differ from those in Toronto because the cities have very different climates which will result in different patterns of snowfall, snow accumulation, snowmelt and runoff. For example, at Boulder, snowfalls generally occur during the night with runoff commencing the following day. Furthermore, at Boulder there was no significant snow accumulation on the ground between storms. This contrasts with common experience in Toronto.

Quality data from four Ontario studies (9,10) and one United States stormwater study (12) are presented in Table 2. Comparison of Tables 1 and 2 reveals no gross differences in quality between snowmelt and stormwater with the exception of chloride concentrations.

TABLE 1

Snowmelt Characteristics from Other Studies

	Brucewood-North York (10)		Barrington, East York		Boulder, Colorado
	Range of Means True Snowmelt 1/8 to 3/25/75	Mean Snowmelt/Rainfall 1/3/75	True Snowmelt (9) 2/12/74	True Snowmelt (9) 2/13/74	Range-True Snowmelt (11) 1975/76
TS	1600 - 3800	232	25,870	9,210	245 - 6492
SS	50 502	-	1,570	560	1 - 1229
BOD_5	5.5 - 41	12	80	70	-
COD	61 - 66	-	850	460	8 - 936
Total P	0.1 - 0.95	0.2	1.8	0.6	0.06 - 3.34
Soluble P	0.01 - 0.34	0.02	< 0.1	< 0.04	-
NH_3-N	0.04 - 1.3	0.17	0.5	0.8	-
TK-N	0.1 - 8.4	2.3	11.0	6.3	0.22 - 5.94
NO_3-N	1.1 - 2.8	1.1	1.5	1.3	0.17 - 4.70
Cl^-	163 2090	5390	14,000	5,980	25 - 3185
Pb	0.05 - 1.46	0.57	0.32	0.21	0.005 - 2.27
Alkalinity (as $CaCO_3$)	-	-	492	177	-

all data in mg/L

While bacterial levels in stormwater (Table 2) resemble those in dilute sanitary sewage, bacterial concentrations from snowmelt were not available in the various reports reviewed.

The published data show that snowmelt runoff results in low and only slightly varying storm sewer flow-rates, with variations in flow-rate being dependent on temperature changes and/or the application of road salt. The indicated quality of snowmelt, with the exception of chloride, is very similar to stormwater. However, the literature does not provide much guidance on the likely effectiveness of alternative treatment methods, since information on the soluble and settleable fractions of different parameters is lacking.

5. DESCRIPTION OF THE STUDY AREA

The study was carried out at the Barrington catchment, at a site used for previous (9) and on-going (1) studies of stormwater runoff and treatment respectively. This 22.7-hectare (56-acre) catchment is situated mainly in the Borough of East York but a small part of its area is in the City of Toronto. Catchment location is defined by Figures 1 and 2, while Table 3 gives a summary description of land use and population. The major land use is for single-family residential housing; most structures are 50-70 years old. For all practical purposes, the topography of the drainage area is flat.

The area was originally served by a combined sewer system. Road drainage was separated in 1965 upon construction of a new storm sewer. About 90% of the roof leaders and all weeping tile drainage are connected to the sanitary (formerly combined) sewer. The new storm sewers on Chisholm and Main Streets (Figure 2) flow to the 2500 mm diameter trunk sewer on Lumsden Avenue which in turn carries

TABLE 2

Range of Stormwater Quality Concentrations

		Barrington E.Y. (9)	Brucewood (10)	Guelph-North (10)	Windsor A (10)	Durham N.C. (12)
TS	mg/L	-	300 - 1200	72 - 2300	-	194 - 8620
SS	mg/L	60 - 630	10 - 1000	10 - 1090	23 - 1230	27 - 7340
COD	mg/L	40 - 910	10 - 920	18 - 320	-	20 - 1042
BOD_5	mg/L	7 - 320	0.2 - 110	0.2 - 60	0 - 78	-
Total P	mg/L	0.3 - 11.0	0.04 - 1.6	0.04 - 1.6	-	0.2 - 16
Soluble P	mg/L	0.04 - 2.2	< 0.02 - 0.68	0.004 - 0.07	-	-
TK-N	mg/L	1.0 - 20	0.3 - 19	0.4 - 5.3	-	0.1 - 11.6
NO_3-N	mg/L	< 0.2 - 2.1	< 0.2 - 4.7	<0.2 - 4.6	0 - 4.7	-
Cl^-	mg/L	5 - 125	2 -10300	1 - 68	4 - 1585	-
Pb	mg/L	0.5 - 1.8	0.02 - 1.8	-	-	0.1 - 2.86
Total Coliform	#/100 ml	$1x10^4$ - $5x10^6$	$1x10^2$ - $1x10^5$	$1x10^4$ - $8x10^5$	$2x10^2$ - $1x10^6$	-
Fecal Coliform	#/100 ml	$1x10^3$ - $1x10^6$	10 - $2x10^4$	$1x10^3$ - $7x10^4$	$1x10^2$ - $2x10^4$	$1x10^2$ - $2x10^5$

Barrington E.Y. data represent the range of the maximum concentrations recorded in individual events

Brucewood data include winter storm events

the flow to a 10-metre deep dropshaft at the end of Barrington Avenue and onward for 300 metres to the receiving stream via an outfall of 1500 mm diameter.

The receiving stream, Massey Creek, flows through Metro Parkland to the north of the study site and thence to the Don River. All roads within the drainage area are served by gutters and there are no open ditches. The street catchbasins are connected to the storm sewer system. No known cross-connections exist between the sanitary system and the new storm sewer systems in the catchment.

During the fall of the year, municipal practices include catch-basin cleaning. During winter, road salting/sanding using a 50:50 mixture of each, snow clearance and snow removal are all carried out as required. Ice-covered catchbasins are cleared to prevent localized flooding during thaws or winter rains.

6. MATERIALS AND METHODS

Equipment used above and below ground during the snowmelt study is shown schematically in Figure 3. A wet well and submersible sample pump, located in the main drop shaft of the storm sewer, were used to acquire and pump runoff continuously to a storage/treatment tank and sampling point, at ground level. The equipment used in this study represented only a small portion of a fully automated sampling and flow monitoring system, which had been installed for the study (1) of rain-caused runoff in other seasons. Grab samples for characterization were generally taken at one-hour intervals while the storage-treatment tank was filled on a continuous basis. Excess sample was continuously returned to the storm sewer by gravity.

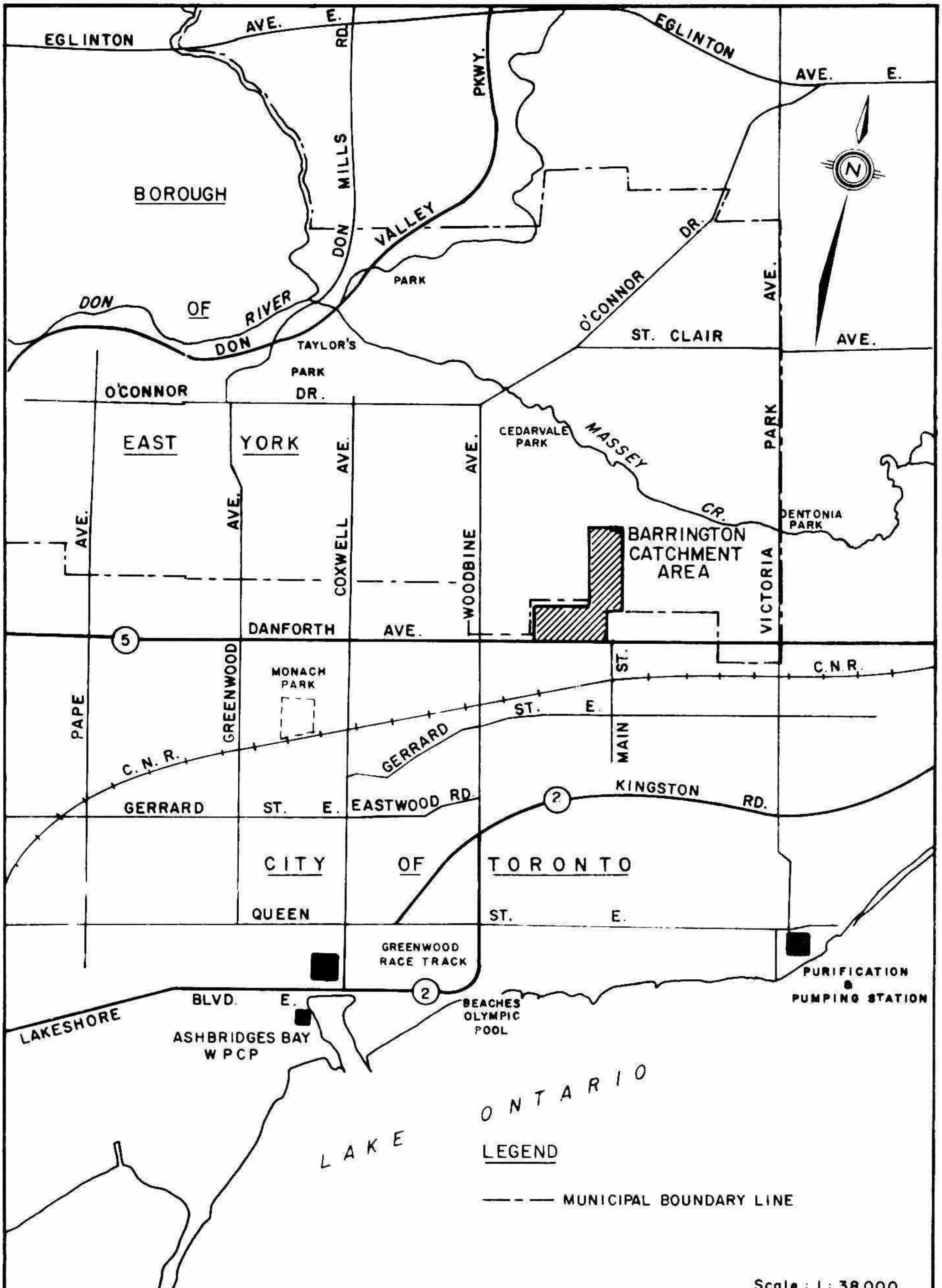

FIGURE I : BARRINGTON CATCHMENT LOCATION WITHIN METROPOLITAN TORONTO

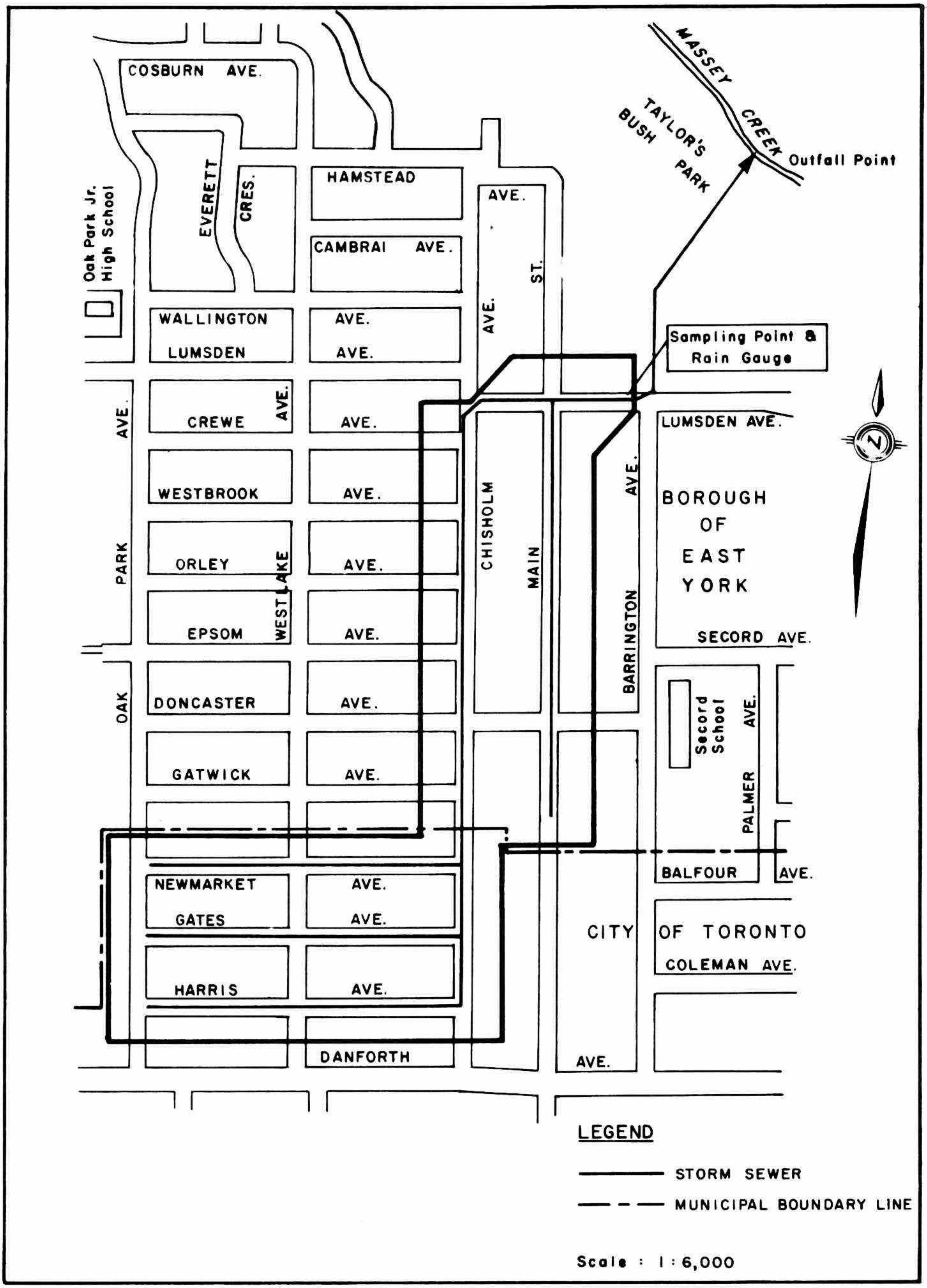

FIGURE 2 : BARRINGTON CATCHMENT AREA

TABLE 3

LAND USE AND POPULATION IN THE BARRINGTON CATCHMENT

	Hectares	Acres
Gross Area	22.7	56
Net Area Contributing to Storm Runoff	17.4	43
Area of Roads and Public Sidewalks	4.1	10.1
Area of Lawns, Private Walks and Driveways	13.3	32.9

Population	2550
No. of Houses	511
No. of Stores	7
No. of Churches	2
No. of Gas Stations	1

Measurement of the flow-rate during runoff periods was accomplished mainly within the storm sewer. To determine flow-rate, all of the instantaneous flow was collected as it spilled into the bypass dropshaft (Figure 3) and the time taken to fill a 20 L container was noted. Under the prevailing low flow-rates in the storm sewer, adequate supplies of runoff to the suction side of the sample pump could only be assured when the bypass dropshaft was closed off with a cover plate. The cover was removed, as necessary, to permit flow measurement.

Bench-scale test equipment, employed at the surface, consisted of a Phipps and Bird, six-unit, variable-speed jar tester, and a 150 mm diameter, 1.5 metre high acrylic settling column having four sampling ports each one foot apart.

Pilot plant equipment, also located at the surface, consisted of a storage-treatment tank with a nominal capacity of 1500 litres and a surface area of 1.27 m^2. A variable-speed, twin-impellor, mixer was clamp-mounted to the storage tank.

To operate the pilot and bench-scale equipment, the sample pump was started and the storage/treatment tank was filled with the mixer in operation. Samples were withdrawn from the well-mixed tank contents for analysis of pollutants, and also for jar test studies in preparation for pilot-scale chemical flocculation.

Bench-scale tests included jar test procedures for estimating the chemical dosage required for effective flocculation. Alum was chosen as the flocculent at dosages up to 70 mg/L in increments of 10 mg/L applied to two-litre batches as follows:

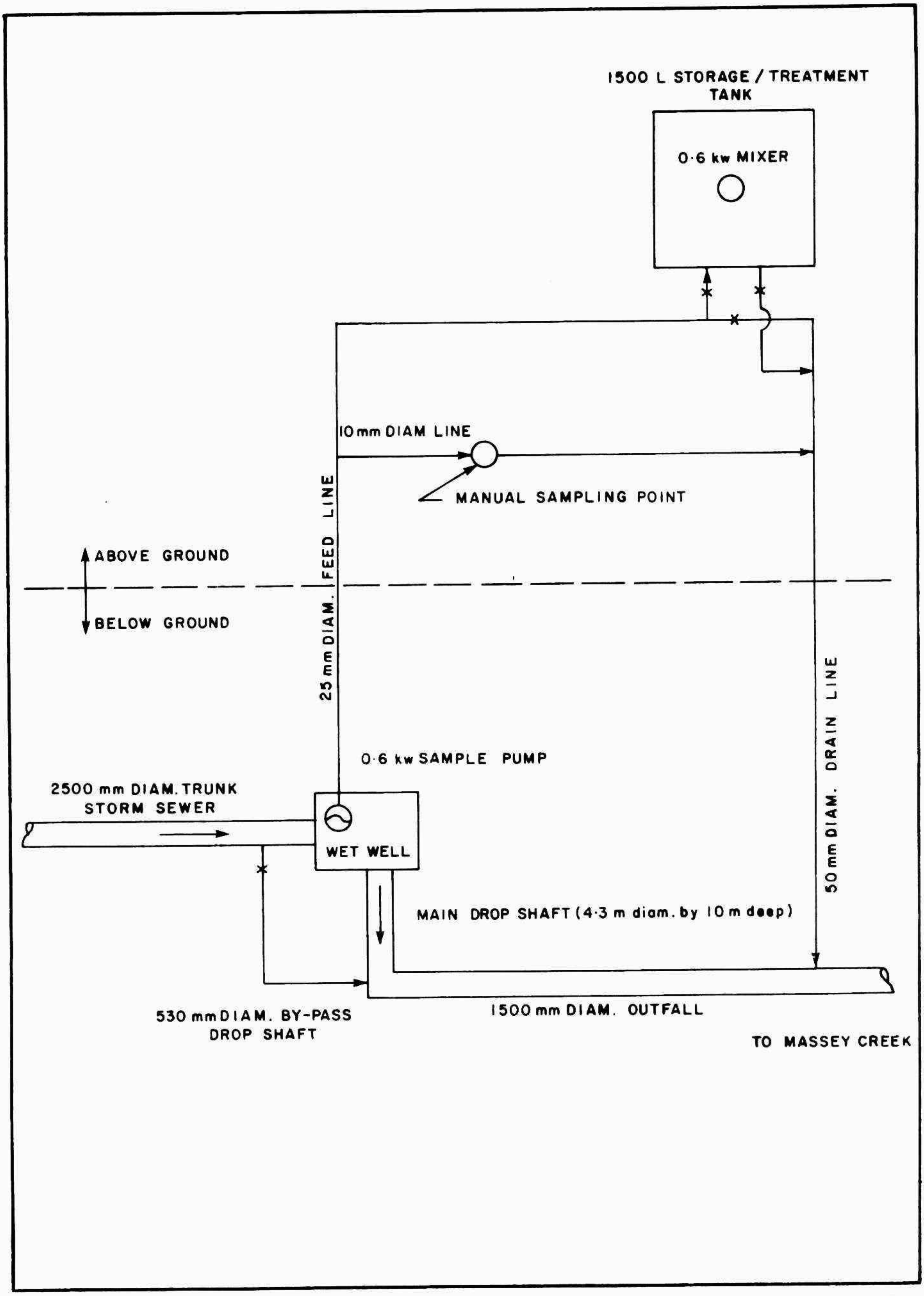

FIGURE 3 : SCHEMATIC OF STORM SEWER AND EQUIPMENT USED

To the well agitated samples (100 rpm) alum was added as a 1.0% solution to achieve the required dosage. After a three-minute rapid mix, the speed of agitation was reduced to 30 rpm for 15 minutes. This was followed by 30 minutes of settling. During settling, and immediately after, the indivi :al samples were judged for relative floc formation, settling rates and turbidity of the supernatant. This was followed by sampling of supernatant for laboratory analyses.

The settling column was used to study natural settling. A composite sample was taken while the column was being filled from the 10 mm sample line taking care to ensure that the column contents were intially well mixed. Small volumes (180 mL), just sufficiently large to permit suspended solids analysis, were withdrawn at each sampling port at five-minute intervals for the first 15 minutes, then at 30-minute intervals for the next hour. A final sample was taken after a further hour of settling.

Pilot-scale batch treatment studies consisted of either natural or chemically assisted sedimentation or both. When both were done on a single batch, chemical flocculation followed natural settling with tank re-mixing between tests. Unless stated otherwise, all pilot plant treatment evaluations were based on representative grab samples, which were taken before and after treatment by syphoning off a sufficient aliquot from a point 30 cm below the liquid surface.

Chemical batch treatment studies began by dosing the tank contents with 10% liquid alum at a dosage based on the visual observations from the jar test. After a five minute rapid mix, followed by a 15 minute slow mix, the flocculated tank contents were allowed to settle for two hours, and the supernatant was then sampled for laboratory analysis. In all cases, alum dosage was calculated and expressed as dry commercial alum having the formula $Al_2(SO_4)_3 \cdot 14\ H_2O$.

Treatment by natural settling was followed by sampling of the tank contents after one and two hours of settling. For a more thorough evaluation of natural settling, samples were withdrawn at 30, 60, and 90 cm depths at frequent intervals for up to three hours.

All laboratory analysis were done at the Ministry of the Environment, Central Laboratory according to Standard Methods (13) or Ministry of the Environment modified procedures (14).

During periods of on-site work, visual observations were made regularly in the catchment area of snow accumulation and distribution, buildup of dirt and accessibility of snowmelt to the catchbasins.

7. RESULTS AND DISCUSSION

7.1. General

Snowmelt runoff during the 1977/78 season consisted of two brief mid-winter events, on December 14, 1977 and January 25, 1978; and the final runoff for the season during the period March 10-21, 1978.

Runoff from the two mid-winter (true) snowmelts commenced immediately after heavy snowfalls. Melting and runoff of freshly fallen and wet snow was accelerated by above freezing temperatures and road salting. The resulting road slush changed readily to free water flowing into the catchbasins. Visual observations on the surface indicated that the bulk of runoff came from roadways rather than from private property. While snowmelt was in progress, flow rates in the storm sewer varied only slowly with time. The advent of below freezing temperatures terminated runoff in each case.

The mid-winter runoff was sampled and analyzed non-intensively; the final snowmelt was sampled intensively, and treatability studies were also carried out.

Total cumulative snowfall in Toronto for the 1977/78 winter season was above average - 175.5 cm as compared with the 30 - year normal value of 141 cms. Throughout the winter, snow in the study area was piled up on the small residential fromt yards and along street curbs with little undistrubed snow cover. A very dirty snow cover near the end of winter indicated heavy pollutant accumulations.

The final 1977/78 thaw and subsequent runoffs occured on five separate days with true snowmelts on March 10, 12, 13 and combined snowmelt/stormwater on March 14 and 21. The final snowmelt resulted in small volumes of runoff at low intensities due to three reasons. Firstly, below freezing temperatures and sunny days during February and March caused the bulk of the accumulated snow cover to sublimate. Secondly, the remaining frozen and piled-up snow responded slowly to

thawing. Thirdly, a large percentage of the catchbasin covers were covered by ice limiting the access of free water to the storm sewers. No significant street ponding was observed, and consequently, there was no need for Borough personnel to clear ice-covered catchbasins to facilitate the entry of free water to the storm sewers.

Visual observations during snowmelt and snowmelt/stormwater runoffs revealed an absence of debris (leaves, plastics, wood, metal cans, paper) or large sized settleable mater which was in complete contrast to previous observations during rain caused runoff (1). It was postulated that this was due to less littering during the winter, slow and impeded surface movement of the runoff and its restricted access to the catchbasins. Furthermore, larger settleable matter finding its way to a catchbasin could reasonably be expected to settle in the catchbasin sump because of the low flow rates. In fact, continuing visual inspection in the storm sewer revealed that the bulk of the winter's accumulated matter was not transported to the storm sewer outfall until the first major rain-caused storm event following the final snowmelt. Similarly, it was observed that animal excreta, which accumulated on boulevards or off-street, remained surface-bound. Accumulated matter on road surfaces was partly removed by street sweeping, which resumed April 3, 1978, after the final snowmelt but well before the first major storm event of the spring which occurred on May 8, 1978.

7.2. Snowmelt Characteristics

Snowmelt and snowmelt/stormwater characteristics are summarized in Tables 4 and 5 for the mid-winter and final snowmelts

respectively. Mid-winter runoff data in Table 4 are based on a single grab sample in each event while the data in each column of Table 5 represent the range of pollutant concentrations in hourly grab samples collected over four-hour periods.

A review of the observed runoff characteristics in Table 4 and 5 indicates a wide variability in total, suspended, dissolved and volatile suspended solids. Other parameters such as BOD_5, COD and nutrients were at relatively low and fairly constant concentrations. Generally, snowmelt characteristics from this study fall within the concentration ranges summarized from other studies in Table 1.

Chloride concentrations were extremely high during mid-winter runoff as a result of road salting, with chlorides contributing a substantial portion of the dissolved solids. The highest value of chlorides (18200 mg/L) occurred during the January 25 event. During the final snowmelt, initial chloride levels of 1600 mg/L declined slowly to levels of less than 50 mg/L near the end. Similarly, the higher alkalinity levels of up to 270 mg/L during true snowmelts (January 25) returned to levels of about 100 mg/L or less (March 14, 21). The lower levels are typical of other seasons.

The decline in chloride concentration during the course of the final snowmelt suggests that the applied road salt remained on the road bed until runoff commenced, and was then removed on account of its solubility.

The fractions of suspended matter removed from suspension during a one-hour settling period at a given depth (settleable solids, Table 6 and 7) were essentially zero for true snowmelt and only 11%

TABLE 4

TRUE SNOWMELT CHARACTERISTICS - MID-WINTER - 1977/78

Pollutant		December 14/77	January 25/78
Total Solids	mg/L	1110	31,740
Suspended Solids	mg/L	130	840
Dissolved Solids	mg/L	980	30,900
Volatile Suspended Solids	mg/L	52	230
BOD_5	mg/L	18	46
BOD_{20}	mg/L	42	75
COD	mg/L	145	-
Total Organic Carbon	mg/L	45	58
Total-P	mg/L	0.30	0.52
Soluble-P	mg/L	0.08	0.02
NH_3-N	mg/L	0.40	0.60
TKN	mg/L	1.20	2.80
NO_2-N	mg/L	0.16	0.59
NO_3-N	mg/L	0.60	1.50
pH		8.1	6.7
Alkalinity (as $CaCO_3$)	mg/L	84	269
Conductivity	umhos/cm^2	1920	48,800
Turbidity	FTU	71	140
Chloride	mg/L	510	18,200
Total Coliform	counts/100 ml	2.0×10^4	1.1×10^2
Fecal Coliform	counts/100 ml	1.0×10^3	4.0×10^1
Fecal Streptococci	counts/100 ml	2.0×10^3	8.0×10^2
Cu	mg/L	0.07	-
Ni	mg/L	0.06	-
Pb	mg/L	0.78	-
Zn	mg/L	0.40	-
Cd	mg/L	< 0.01	-
Cr	mg/L	0.10	-
Mn	mg/L	0.13	-
Fe	mg/L	6.10	-
Flow Rate	L/s	4	1
No. of Samples		1	1

TABLE 5

RANGE OF SNOWMELT CHARACTERISTICS - FINAL SNOWMELT - 1978

Pollutant		True Snowmelt March 10, 1978	Snowmelt/Stormwater March 14, 21, 1978
Total Solids	mg/L	2115 - 3050	228 - 746
Suspended Solids	mg/L	215 - 305	65 - 261
Dissolved Solids	mg/L	1815 - 830	155 - 600
Volatile Suspended Solids	mg/L	80 - 115	28 - 92
BOD_5	mg/L	18 - 22	9 - 26
BOD_{20}	mg/L	45 - 60	-
COD	mg/L	240 - 280	57 - 170
Total Organic Carbon	mg/L	63 - 67	27 - 62
Total-P	mg/L	0.70 - 0.90	0.40 - 0.75
Soluble-P	mg/L	0.02 - 0.08	0.10 - 0.22
NH_3-N	mg/L	1.4 - 1.5	0.4 - 1.7
TKN	mg/L	6.0 - 7.0	1.6 - 6.0
NO_2-N	mg/L	0.24 - 0.40	0.05 - 0.2
NO_3-N	mg/L	1.0 - 1.1	0.5 - 3.0
pH		7.4 - 7.5	7.2 - 8.0
Alkalinity (as $CaCO_3$)	mg/L	138 - 163	43 - 104
Conductivity	umhos/cm^2	4220 - 5350	270 - 1100
Turbidity	FTU	-	24 - 53
Chloride	mg/L	1030 - 1660	45 - 276
Total Coliforms	counts/100 ml	1500 - 39000	3.0×10^3 - 7.0×10^3
Fecal Coliforms	counts/100 ml	10 - 20	2.3×10^2 - 4.8×10^3
Fecal Streptoccoci	counts/100 ml	84 - 1004	1.5×10^3 - 1.5×10^4
Cu	mg/L	0.4 - 0.14	-
Ni	mg/L	< 0.02	-
Pb	mg/L	1.0 - 1.6	-
Zn	mg/L	0.54- 0.69	-
Cd	mg/L	< 0.005	-
Cr	mg/L	< 0.02	-
Mn	mg/L	0.20- 0.25	-
Fe	mg/L	9.9 -12.0	-
No. of Samples		4	10
Flow Rate	L/s	2	20 - 80

for snowmelt/stormwater. Apparently, the sand in the sand-salt mixtures applied to the road was not transported through the sewer to the sampling point.

Indicator bacteria levels were generally lower in snowmelt or snowmelt/stormwater than in rain-caused runoff. Examination of the fecal coliform/fecal striptococci (FC/FS) ratio shows that in all cases it was 0.7 or less. In rain-caused runoff, Geldreich and Kenner (15) have indicated that ratios of 0.7 or less result when the bacteria originated from domestic animals. However, there are no published data on the significance of the ratio in runoff from snowmelt or snowmelt/stormwater. Quite possible, the FC/FS ratio in snowmelt may relate more to factors such as the ability of different types of bacteria to survive freezing or freeze-thaw cycles.

Storm sewer flow rates during true snowmelts were very low, in the range of 1 to 8 L/s. Flow rates during snowmelt/stormwater runoff periods varied with the prevailing intensity of precipitation, within a range of 20 to 80 L/s. These flow rates were well below those in rain-caused runoff events for this catchment which had reached peak flows of up to 2000 L/s (1). Based on total catchment area, the equivalent runoff rate for the prevailing 20 L/s storm sewer flow rate during snowmelt/stormwater runoff corresponded to only 0.32 mm/hr.

7.3 Bench-Scale Studies

The effects of bench-scale flocculation on selected pollutants are shown in Figures 4, 5 and 6 for true snowmelt and snowmelt/stormwater. The figures show the percentage removals

of SS, COD and Total P respectively for alum dosages up to 70 mg/L. Although results for only three parameters have been presented, most other parameters tested for responded in a similar manner to alum flocculation and settling (see also Table 8 under batch treatment studies).

As previously noted, visual observations during jar tests served as the primary guide for the selection of chemical dosage in scaled-up batch treatments because results of laboratory tests on the jar test supernatants were not available for about two weeks. However, laboratory results usually supported the visual judgments made on site. It therefore appears possible to use visual observation to arrive at the correct chemical dosage by jar testing alone without having to await the results of time-consuming chemical analysis.

Figure 4, 5 and 6 show that an alum dosage of 50 mg/L produced effective flocculation and pollutant reductions on runoff from the March 10 snowmelt. For the runoffs of March 12 and 21, the required alum dosage dropped to 30 to 40 mg/L, a level comparable to rain-caused runoff events (1). The jar test results and visual observations also showed the existence of a limiting alum dosage varying with runoff characteristics, above which no additional pollutant removals occured.

Factors that could have been affecting the optimal chemical dosage for good floc formation included high levels of dissolved solids, high alkalinity and lower temperatures. It has been demonstrated that high alkalinity exerts a buffering action to pH changes resulting in higher alum demands in order to

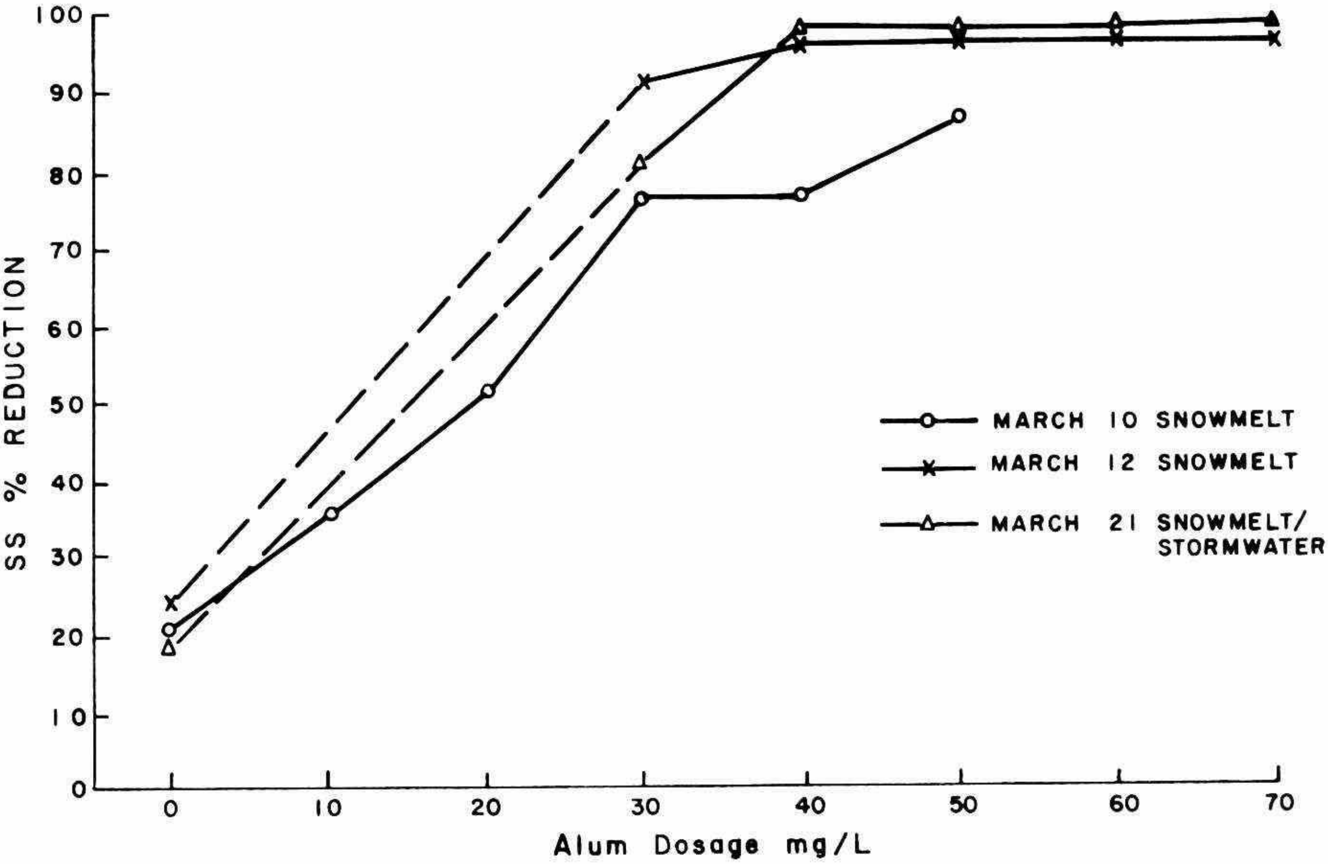

FIGURE 4 : SS REDUCTION Vs ALUM DOSAGE

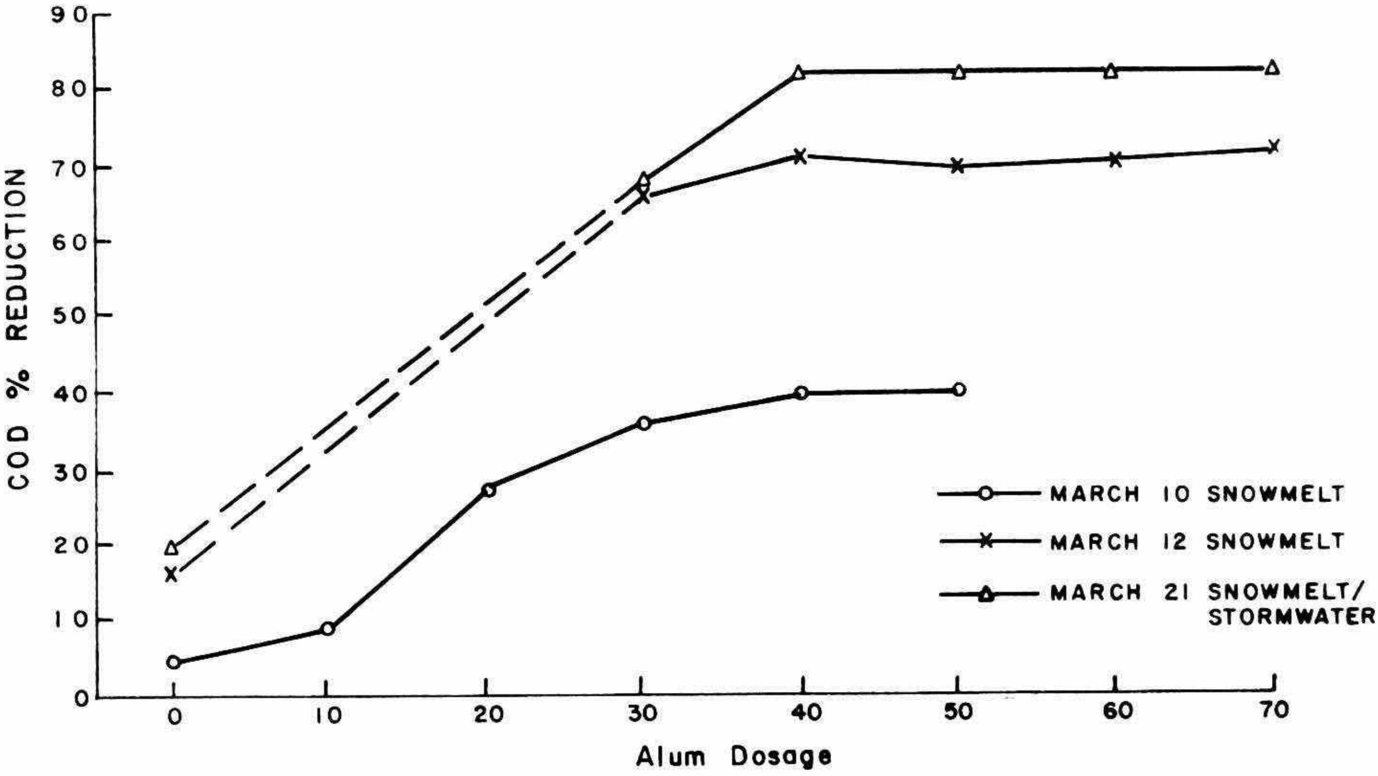

FIGURE 5 : COD REDUCTION Vs ALUM DOSAGE

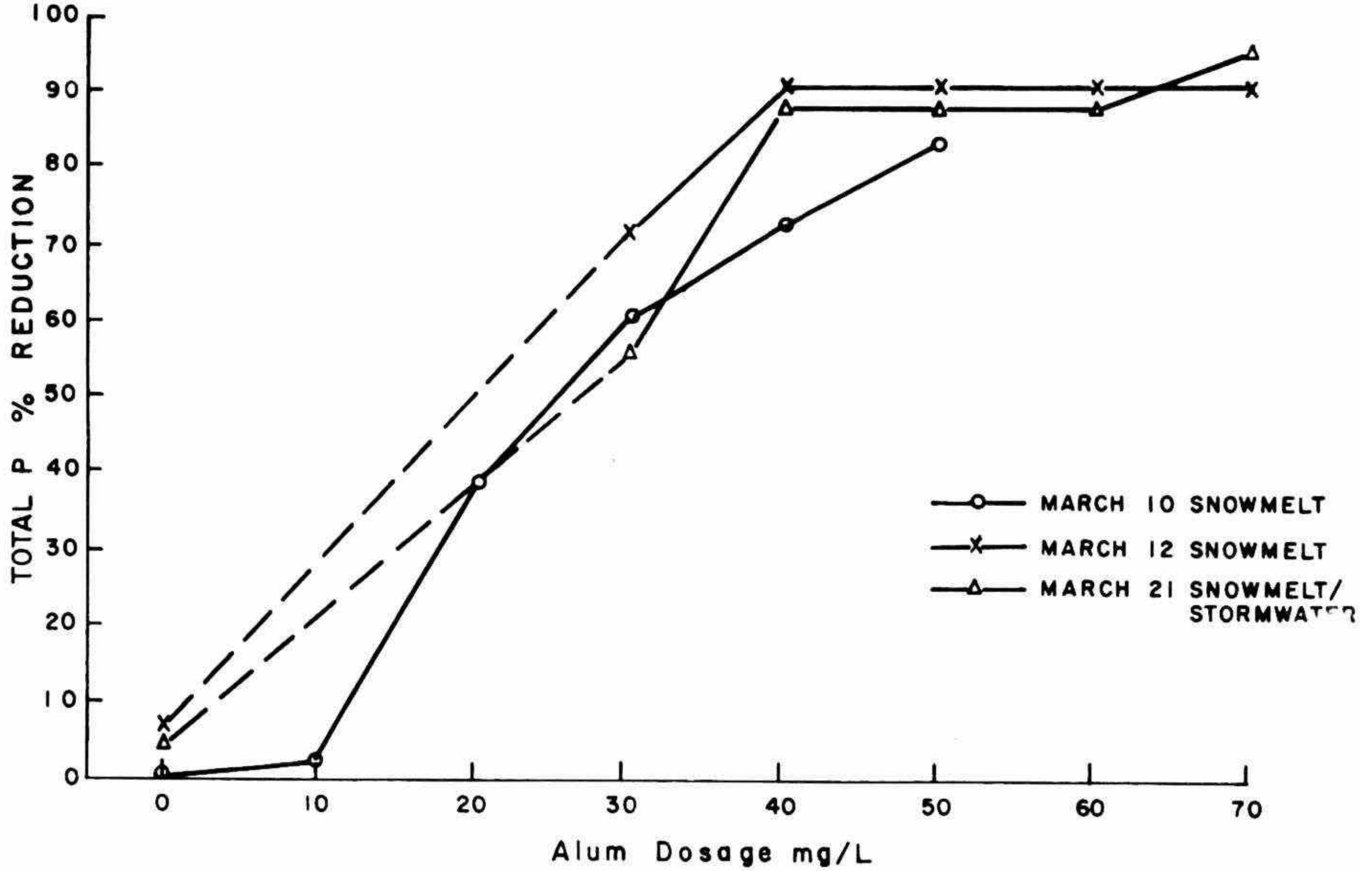

FIGURE 6 : TOTAL P REDUCTION Vs ALUM DOSAGE

reach the isoelectric point of the colloidal material (12). In this study the buffering action of the runoffs was such that no significant change in pH resulted over the range of alum dosage used. A review of the other runoff characteristics in the final snowmelt (Table 5), shows high concentrations of dissolved solids (chlorides and alkalinity) on March 10 which decreased to normal levels (50 mg/L Cl and 100 mg/L alkalinity) by March 21. Optimal chemical dosage also declined correspondingly during this period. Since temperatures were also low (2-3°C), all three factors referred to above could have contributed to the higher dosage needed on March 10th.

Table 6 illustrates the poor natural settling characteristics of runoff from the March 13 snowmelt. The table shows that only minimal suspended solids removals occurred after two hours of settling; further, according to on-site tests, the settleable solids fraction was nil. The runoff was high in turbidity which prevented any useful visual observations of settling characteristics.

7.4. Batch Treatment Studies

Chemical flocculation of snowmelt or snowmelt/stormwater was achieved by the addition of 50 to 60 mg/L alum followed by 2 hours of quiescent settling. The 2 hour settling time was selected because it had proven to be long enough for rain-caused runoff (1). Visual observations during batch treatments, and other results discussed below, indicated that settling rates of the alum floc were lower than rain caused runoff. Consequently, a longer settling time would

TABLE 6

SETTLING TEST ON SNOWMELT RUNOFF

March 13, 1978

(Using 15 cm Diameter Settling Column. Suspended Solids in Mixed Composite at time Zero: 134 mg/L)

	Settling Time in Minutes					
Depth cm	5	10	15	30	60	120
	Suspended Solids (mg/L)					
30	135	137	145	136	134	115
60	134	144	138	137	136	135
90	138	140	138	144	142	133
120	135	142	138	138	136	145

From above settleable solids are: 0% (based on 60 minute settling at 30 cm depth), SS data in mg/L.

TABLE 7

SETTLING TEST ON SNOWMELT/STORMWATER RUNOFF

March 14, 1978

(Using Large On-Site Tank. Suspended Solids in Mixed Tank at Time Zero: 186 mg/L)

	Settling Time in Minutes						
Depth cm	15	30	60	90	120	180	(26-hr)
	Suspended Solids (mg/L)						
30	168	167	165	164	158	148	87
60	177	173	168	170	159	155	92
90	178	175	171	169	161	152	97

From above settleable solids are: 11.0% (based on 60 minutes settling at 30 cm depth), SS data in mg/L

have been advantageous. Alternatively, the addition of a suitable polyelectrolyte as practiced by other researchers (12) might have reduced the required settling time.

Table 8 shows the percentage pollutant reductions resulting from chemical flocculation and natural settling. In two tests (March 13, 21), additional pollutant reductions are evident for both natural and chemically assisted sedimentation as a result of extending the settling time to 20 hours (overnight). No significant increase in pollutant removal was observed on entending natural settling (March 21) from one to two hours.

Pollution reductions resulting from chemical flocculation (March 12 and March 21) were fairly high - 84 to 98% SS, 80 to 97% VSS, 58 to 81% COD, 54 to 81% Total P, 80 to 86% Soluble P, and 76 to 83% turbidity. Values towards the higher end of the range of pollutant removals were obtained with extended settling times and with snowmelt/stormwater runoff. Alum flocculation also produced reductions of 50 to 87% of the trace metals Cu, Pb, Zn, Cr, Mn and Fe. The significance of trace metal reductions may be questionable since with the exception of lead, their initial concentrations were very low (Tables 4 and 5).

Table 8 also shows that compared to chemically assisted settling, natural settling produced rather poor pollutant removals even at extended settling times of up to 20 hours. Parameters which showed some response to natural settling were SS, VSS, BOD_5 and COD. The March 21 data in Table 8 also permits direct comparison between

TABLE 8

PERCENT POLLUTANT REMOVAL BY ON-SITE BATCH TREATMENT

Parameter	Natural Sedimentation[1] Snowmelt		Natural Sedimentation[1] Snowmelt/Stormwater		Chemically Assisted Sedimentation[1,2] Snowmelt	Chemically Assisted Sedimentation[1,2] Snowmelt/Stormwater	
Date	March 13		March 21		March 12	March 21	
Settling Time-hr	1	20	1	2	2	2	20
Alum Dose-mg/L	-	-	-	-	60	50	50
Total Solids	1	8	0	7	13	33	41
Susp. Solids	12	46	14	19	84	88	98
Vol. Susp. Solids	2	37	18	22	80	87	97
BOD_5	9	9	22	22	0	39	56
BOD_{20}	0	-	11	21	27	59	62
COD	13	39	19	25	58	81	-
Tot. Org. Carbon	0	31	0	0	68	64	-
Total-P	3	17	6	0	54	81	81
Soluble-P	20	0	0	0	>80	>86	>86
TKN	4	0	0	8	32	54	46
Alkalinity	-	7	0	7	48	7	44
Turbidity	4	27	2	0	76	0	83
Cu	20	20	0	78	60	78	-
Ni	0	0	0	0	0	0	-
Pb	18	46	13	11	83	87	-
Zn	18	36	14	16	73	82	-
Cd	0	0	>50	>50	>50	>50	-
Cr	0	0	13	6	>50	63	-
Mn	6	0	>33	>33	55	>33	-
Fe	3	47	9	11	85	86	-
No. of Samples	1	1	1	1	1	1	1
Storm Sewer Flow Rate L/s	5	5	20 to 80		8	20 to 80	
Temperature °C	2	2	3	3	3	3	3

1. Data expressed as percent pollutant removal, except where otherwise noted.
2. Alum dose is expressed in the form of dry alum having the formula $Al_2(SO_4)_3 \cdot 14\ H_2O$

the effects of natural and chemically assisted sedimentation since results are presented from both types of treatment on the same batch of snowmelt/stormwater.

The data in Table 7 represent the results of an attempt to obtain a detailed evaluation of the natural settling characteristics of suspended matter in snowmelt/stormwater. With the exception of SS, no concentration changes occured with time and depth. Settleable solids, as noted in Table 7, were only 11% with little additional removals after two and three hours of settling. Extending the settling time to 53 hours removed 56% of the suspended solids.

Bacterial removals resulting from alum flocculation, are presented in Table. 9. Fecal streptococci were removed to very low levels with less marked reductions in total and fecal coliforms. No bacterial removals were achieved by natural sedimentation.

7.5 Pollutant Mass Loadings

Pollutant mass loadings, expressed as Kg/ha-d, based on the total catchment area, were estimated for the parameters SS, BOD_5, COD, Total P and Chloride for the duration of the final 1977/78 snowmelt (March 10 to 21). Results are presented in Table 10. The average pollutant concentrations and flow rates observed during each event were used to calculate mass flow rates. These values were assumed to prevail for the whole of the respective 24-hour periods. However, since runoff flow rates diminished during nights when temperatures dropped, the mass loading values as calculated represent probable maximum loadings.

TABLE 9

INDICATOR BACTERIA REDUCTIONS BY ALUM FLOCCULATION

Runoff Date	Bacteria	Mixed Tank Untreated	Alum Treatment 2 hr Settling
March 12	Total Coliform	1.7×10^3	3.4×10^2
	Fecal Coliform	6.3×10^2	1.6×10^2
	Fecal Streptococci	2.8×10^3	<10
March 21	Total Coliform	6.2×10^3	2.1×10^2
	Fecal Coliform	7.1×10^2	6.0×10^1
	Fecal Streptococci	1.5×10^4	8.0

Furthermore, comparing snowmelt mass loadings in this catchment with corresponding rain-caused runoff (1), it is apparent that a single major rainstorm can produce pollutant mass loads in excess of the combined 1978 final snowmelt. The low pollutant mass loadings of most parameters during snowmelts resulted from low runoff rates rather than low pollutant concentrations. Chloride was the only parameter for which high mass flow rates were encountered. These were due to the high concentrations of this substance observed in the runoff after road salting.

Estimated chloride loading for the January 25 snowmelt (not presented) was 66 Kg/ha-d at a low runoff rate of only one litre per second. Road salting had been discontinued for about six weeks prior to the final snowmelt period, and consequently, the chloride mass flow rates in Table 10 are substantially lower.

As previously mentioned (Section 7.1), overland flow during snowmelt has varying accessibility to the storm sewer system. Similarly, surface transport of suspended matter is impeded during low intensity runoff. Hence loading magnitudes may vary widely in successive snowmelts or winter seasons in the same catchment and between catchments. In the present study it was also found (Section 7.1) that the bulk of the winter surface accumulations of dust and dirt were not conveyed to the storm sewer outfall until the first major rainstorm after the final snowmelt.

TABLE 10

MASS FLOW RATES OF KEY POLLUTANTS - FINAL SNOWMELT

Event	Pollutants - mg/L (Mean)					Flow Rate	Mass Flow Rates - kg/ha-d				
	SS	BOD_5	COD	Total P	Cl^-	L/S	SS	BOD_5	COD	Total P	Cl^-
1978											
March 12	255	16	240	0.70	552	8	7.8	0.5	7.3	0.02	16.8
March 13	170	22	150	0.66	640	5	3.2	0.4	2.9	0.01	12.2
March 14*	186	22	140	0.76	273	20	14.1	1.7	10.7	0.06	20.8
March 21*	182	18	160	0.62	74	20	13.8	1.4	12.2	0.05	5.6

* Combined snowmelt/stormwater

Note: Mass flow rates given in kg/ha-d, assuming constant flow rates and concentrations as obtained during sampling periods.

For this catchment (22.7 ha) kg/ha-d = (concentration mg/L) (L/s) (0.00381)

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